Summary of Research

CONTROL ORIENTED MODELING AND VALIDATION OF AEROSERVOELASTIC SYSTEMS

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Reporting Information

Background and Objectives

Lightweight aircraft design emphasizes the reduction of structural weight to maximize aircraft efficiency and agility at the cost of increasing the likelihood of structural dynamic instabilities [1]. To ensure flight safety, extensive flight testing and active structural servo control strategies are required to explore and expand the boundary of the flight envelope. Aeroservoelastic (ASE) models [2] can provide online flight monitoring of dynamic instabilities to reduce flight time testing and increase flight safety.

The success of ASE models is determined by the ability to take into account varying flight conditions and the possibility to perform flight monitoring under the presence of active structural servo control strategies. In this continued study, these aspects are addressed by developing specific methodologies and algorithms for control relevant robust identification and model validation of aeroservoelastic structures. The closed-loop model robust identification and model validation are based on a fractional model approach where the model uncertainties are characterized in a closed-loop relevant way. During this research effort the following research items will continue to be pursued.

1. Closed-loop relevant characterization of the linear model P and model uncertainty Δ of the ASE model (P, Δ) by fractional (coprime factor) representations.

2. Closed-loop estimation of the nominal model P and the unstructured uncertainty Δ using the fractional model representation, to capture unmodeled (high frequency) elastic modes, actuator saturation and oscillatory aerodynamic approximation errors.

3. In the line of the fractional model approach, development of closed-loop model validation techniques to verify the validity of an ASE model (P, Δ) by experimental flight data.

The proposed closed-loop identification and model validation techniques in this continued study are aimed at applications where aeroelastic flight data of an F18 Active Aeroelastic Wing (AAW) aircraft at NASA Dryden are used to robustly characterize flight envelopes and predict flutter margins.

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Progress of Research

Use of fractional model representations

Dealing with lightweight flight applications where structural control is used to stabilize an aircraft or control flutter phenomena requires a special approach to deal with (noisy) experimental flight data obtained under feedback controlled conditions. Flight data of ASE systems is affected by noise that arises from sources such as engine vibrations, turbulence, unexpected pilot inputs, sensor noise and nonlinear behavior of the system itself [3]. Currently in this project, the model structure formulation of fractional representations has been studied as it pertains to the flight system. It has been found by examples that using the Linear Fractional Transformation (LFT) approach greatly facilitates manipulation and computation of linear systems.

Robust control oriented identification

The fractional model representation mentioned above can be used to formulate control oriented modeling problems. In this approach, coprime factorizations of a nominal model along with a perturbation on the factorization can be estimated by taking into account feedback data and feedback relevant weighting functions that emphasize the control oriented nature of the ASE model. This approach has been successfully applied in flexible mechanical systems [4] where control oriented modeling is required to enhance the mechanical performance of the system. At the current stage of this project, the robustness of a simple system has been studied as a preliminary step towards the application of a coprime factorization formation to the flight data. This example has been used to understand the structure and formulation of robustness measures for a system as well as the uncertainty description itself. Important in the deliberation of robustness, it was found that when the uncertainty Δ is considered as having a specific structure, the generated models become less conservative and allow for a more realistic representation of the true system. Additionally, flight data obtained from NASA Dryden has been used to identify preliminary system and noise models for the ASE system.

Control oriented model validation

Model validation is a critical procedure to establish whether or not an ASE model can reliable predict flight envelopes. Moreover, a model validation is coherent with the setup in which it will be used. The model validation of general LFT discrete and continuous uncertain systems are studied in [5] and [6]. At the current stage of this project, validation techniques have been used to validate the preliminary system and noise models that were developed from actual flight data. Closed-loop model validation techniques have been addressed in a coprime factor framework and the stability and robustness of these systems has been investigated. Additionally, techniques and the pertinent tradeoffs between frequency domain data and time domain data have been considered.

Milestones of the Study

The objective of this research project is to address the issue of robust identification and model validation techniques for the control of ASE systems. Development of these techniques has been completed at the end of this first year of study. The potential benefit of this work is the development of techniques which will allow the aeronautical engineer to design ASE systems with improved stability margins. Furthermore, reliable ASE models can be implemented in

on-board flight computers to monitor air craft behavior and assist pilots in determining safe flight conditions. Crucial for the reliability for ASE models is the model validation techniques addressed in the second year of this study. Complete and on-board implementable ASE models for the F18 Active Aeroelastic Wing (AAW) aircraft at NASA Dryden will be completed in the third year of the project.

Publications and Subject Inventions

As a result of this research, the paper "Control Oriented Modeling and Validation of Aeroservoelastic Systems Using Coprime Factorizations" was submitted to the IEEE 2002 Conference on Decision and Control. In the paper, closed-loop identification and model validation techniques were used to robustly characterize the dynamic performance of an aeroservoelastic system. The techniques were based on a fractional representation approach and have two main benefits. Firstly, they address the problem of correlation between the input and output signals that are observed in feedback controlled systems. Secondly, the fractional representation allows the formulation of a unified approach to estimate models via the estimation of stable coprime fatorizations based on closed loop data. The paper "Coprime Factor Perturbation Models for Closed-Loop Model Validation Techniques" is to be submitted to the IFAC 2003 Conference. This paper discusses the validation techniques used to characterize the dynamic performance of a closed-loop system. Also due to this research, the paper "Coprime Factor Perturbation Models for Control Oriented Model Validation" is to be submitted to the 2003 Automatica Journal. This paper presents model validation results for open-loop and closed-loop systems for noisy and noise-free data. Additionally, the application of flight data towards the presented techniques is also developed. Beyond the discussed papers, no new technologies/inventions were made under this grant.

References

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